DYNAMIC AND MULTI-CRITERIA SCHEDULING OF MAINTENANCE ACTIVITIES

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Abstract
Skills management in the industry is one of the most important keys in order to obtain good performance with production means. Especially in maintenance services field where the different practical knowledge or skills are their working tools. We address, in this paper, the both assignment and scheduling problem that can be found in a maintenance service. Each task that has to be performed is characterized by a competence level required. Then, the decision problem of assignment and scheduling leads to find the good resource and the good time to do the task. For human resources, all competence levels are different, they are considered as unrelated parallel machines. Our aim is to assign dynamically new tasks to the adequate resources by giving to the maintenance expert a choice between the most robust possibilities.

Keywords:
Competence, Human Resources, Maintenance, Scheduling, Tasks Insertions, Uncertainties.

1 INTRODUCTION

To stay competitive, companies must decrease their costs as much as possible and optimize their production means operations. In order to support better equipments' availabilities, and through them the company one, the maintenance service intervenes. It deals with problems before or after the breakdowns, at any place. This improvement mainly requires a better management of the workforce and its skills.

It is difficult to determine precisely the required human resource number in a maintenance service [1]. Indeed, factors making enabling capacity adaptation are prone to uncertainties. Those are due to several parameters (variations of the intervention requests which are never similar, arrival dates of requests, requests' contents, required treatment duration and equipments availabilities as well as elements related to the real intervention treatments). Thus, the different tasks are well known when they occur. The reactivity and the organization of the maintenance service will depend on the importance of the required treatment.

There are mainly two types of maintenance activities: the preventive maintenance, whose activities can be long term planned, and the corrective maintenance which is related to the non foreseeable breakdowns. Within the service of maintenance, employees have different skills and different qualification levels. Treatment speed and thus the service reactivity will depend on the choice of the employees assigned to the task.

We give in this paper a method to take care of the new tasks apparition and we propose a decision support to insert it in the current schedule. We work on the case where the task assignment has already been realized (for example with the heuristic presented in [2]. The goal is to disturb as less as possible the current schedule. However, the whole schedules are subject to uncertainties and variation between theory and reality. In order to propose insertion solutions for a new task, we have to determine which places in the schedule are the more flexible in order to obtain a scheduling which would be the most robust (the less sensible to uncertainties). The fact to propose schedule solutions taking care of variation by anticipating show that our scheduling method is proactive.

In this article, we detail a methodology which will allow us to assign tasks to resources by considering disturbances. The rest of the paper is organized as followed: In the second section, we will introduce how maintenance services can be managed. In the third part, we will present our scheduling problem. Then we develop our model and a resolution approach. Finally, we will discuss the different obtained results.

2 MAINTENANCE MANAGEMENT

In scheduling and planning, the time horizon is often split in periods (the short, medium and long term). Then, we can study events on each time interval and not on a continuous scale of time. The context of this article takes place in the short term horizon. In this approach, we consider that maintenance tasks have to be scheduled when they occur (generally it is the case of corrective maintenance). The manpower is then the limiting factor in the scheduling realization. Human resources are then organized in the maintenance service which has to plan their work.

2.1 Organization

There are various forms of management of maintenance. Indeed, if the company itself does not assume maintenance, this one can then be sub-contracted. The monitoring, the preventive and corrective maintenance can thus be entrusted directly to the manufacturer of the equipment (expert on this type of equipment) or with a company specialized in industrial maintenance (expert in monitoring and in remote maintenance field but general practitioner as for the monitored equipment). The equipment can also be rented, and if maintenance is not assumed by the user company, it can be sub-contracted too.

Within each plant, the maintenance service has to maintain equipment under operation. The level of the results to reach by the maintenance services is generally predetermined. Either a contract is signed between two (or more) partners fixed their cooperation terms, or there is a *moral agreement* inside the company between production and maintenance service, that fixes the equipment efficiency required. In both case, the objectives of the maintenance are defined by a level of availability (that can be different from equipment to another). The guaranteed availability is a percentage of the opening time. If, for a machine or a group of machines, the objective of availability is not achieved, penalties have to be paid by the service provider. Conditions concerning the penalties are defined while elaborating the contract and are function of the non availability duration. We will consider in our model the minimization of those penalties.

Availability becomes the first factor in the realization of a scheduling through the treatment completion date. In literature, availability is known as temporal constraints for the positioning of tasks at the time of the realization of a scheduling. This means that equipment is in fact occupied over certain periods by activities like maintenance [3]. Unavailability is also related to the resources in order to mean that operators cannot work between certain dates. To our knowledge, the concept of availability (or rather of equipment availability), is generally considered in the literature as a problem data. In our work, we considered it as an emergency indicator to assign priorities during the scheduling realization.

Equipment availability thus makes it possible to determine a temporal period, before the end of which the equipment must be operational. We obtain a completion date (a deadline) and also a period during which the treatment of the task must be carried out. A task with a very restricted treatment period will have priority on a task whose treatment can be delayed.

2.2 Resources

Maintenance service resources are mainly the qualified employees which will be able to solve the different interventions. However, to intervene they need also current or specific tools or equipments but also spare parts and consumable of maintenance.

The maintenance is technical function which required a polyvalence of all the employees, at all the responsibility levels. This polyvalence is mainly required for the technician because of the high complexity level of certain equipment. The competence complementarities will also help to solve real problems.

The human resources are not considered as identical, and then, the assignment decision has to take care of several parameters principally in particular competences.

Skills management

During her thesis, Agnès Letouzey carried out a study on nineteen companies to obtain their opinions on the operators' assignment problem [4]. It shows that operators' management, according to their skills, is important for industry leaders and that there is still no software taking this into account. 79% of the companies think that operators' management is useful or essential in scheduling. Whereas in current software the operational duration is fixed, for the industry leaders, the consideration of the operators' qualification is very important to determine their assignments. For them, the qualification level has (sometimes for 47% of them and always for 27% of them) an influence over the task's duration of realization.

A parallel machine problem

A maintenance service is an environment composed of *m* operators working in parallel. We assume that all can perform each task, but not with the same efficiency. Moreover, the resource which is the most effective for a task, would not necessary be effective for all tasks. The multiplicity of skills shows that we have a parallel machine problem, with unrelated machines which is noted *R* or $R_m|\beta|\gamma$.

2.3 Tasks

A maintenance service has to answer to its customers service demand. To do so, it disposes of human and material resources. Human resources are all different due to their qualification level in the required technical fields. Human resource being in limited number. Each operator can perform only one task at any time. The duration of a task will depend on the resource assigned to and their skills. However, all the resources must be occupied. Then it will not necessary be the most efficient resource who will be assigned to the task's treatment. The tasks' assignment corresponds to a succession of tasks within human resources working time.

On a medium-term, the maintenance service has to plan and assign the best human resource for the treatment of the different maintenance tasks. Preventive and conditional maintenances have for parameters a known duration, a starting date and a completion date. The corrective maintenance task generally occurs in the short-term horizon. They also have a duration, which is only evaluated since it depends on a correct diagnosis. Their earliest starting date is not necessarily immediate, since spare parts are not necessarily available (they can be expected from a supplier) or the availability level of the equipment is quite good and then the intervention can be done later.

These characteristics of maintenance tasks allow us to use the same model. The task is composed by a face duration and the type of competence required (for example, the competence could be mechanic, electricity, automation or a certification). The effective duration of a task will be known only when we will know the resource that will perform it.

3 SCHEDULING PROBLEMS WITH UNCERTAINTIES

3.1 Problem syntheses

In this problem while tasks have not been really treated, their data are stochastic. In order to propose a robust (and proactive) solution, our simulation will consider variations on release-dates, due-dates and of course on the duration of each task within the scheduling.

However, even if schedule modifications may improve results by decreasing the lateness, the workload has to stay balanced between resources. Our problem is then characterized by a group of antagonist objectives. We propose in this study to look at a group of best solutions. The choice will then be leaved to the manager.

The obtained solutions being composed of results on different criteria, dominance relations are used in order to determine which solution will be conserved. Dominance relations traditionally meet in the literature, use the dominance term to show that a solution dominate an other one over all criteria. However, a solution which will dominate completely others has a low probability to exist. Then, we will use a relation of non dominance between to solutions. It means that there is at least one criterion on which a solution is not dominated.

$$\exists j \in [1, N_{objectif}] \Rightarrow f_j(X_1) < f_j(X_2) \qquad (1)$$

The equation 1 implicate that X_1 is not dominated by X_2.

3.2 Scheduling under uncertainty

In classical scheduling problems, the data are generally supposed to be known and fixed. However, the reality does not check this hypothesis, of course because of variations, but also because a lot of data are only previsions or estimations. Optimal solutions to such scheduling problems which are based on fixed data and do not show the reality, will have only few chances to be applicable and will be subject to modifications.

In the existing model taking into account uncertainty, we find mainly the Davenport and Beck one which present three approaches: proactive, reactive and proactive-reactive approaches [5]. Proactivity is the fact to anticipate disturbances before that they really occur. Reactive approaches work in real time, during the scheduling phases. Proactive-reactive methodologies, will try to combine both approaches in order to take into account uncertainties during all the scheduling life cycle and ensure a maximum of performance [6].

A schedule is robust if this performance is few sensible to data uncertainties and variations. Moreover a schedule has to be flexible to be adaptable to the possible disturbance. We can identify a static flexibility as the temporal flexibility (concerning tasks starting date), the sequential flexibility (which authorizes the permutation between tasks, and which supposes the temporal flexibility) or the assignment flexibility (which allows changing of resource after a first assignment). There is also the dynamic flexibility which is the scheduling capacity to adapt itself to disturbances.

In this paper, we consider that, in a given schedule, task data are subject to more or less variations in order to be representative of the reality. Variations location will depend on the task nature. A preventive maintenance activity is well known and well documented, its face duration will be considered as determinist. However their release dates depend on the current production work order end. The due date of a preventive maintenance will depend on the potential equipment breakdown due to the absence of repair. It can not be known before it occurs. Then release date and the due date, for a preventive task, can be modeled as fuzzy data. Contrary to the preventive activities, corrective maintenance tasks processing time can just be estimated. Their durations depend on a correct diagnosis. The release dates of this type of task are generally known because corrective maintenance is generally due to a breakdown and the equipment is stopped. Their due dates are also considered as known because from the breakdown, the equipment availability level goes down. Then corrective maintenance task duration can be modeled as a fuzzy data. The fact that tasks treatment required human resource implicates knowledge on their competence levels. This one being estimated (and then considered as fuzzy), the real task duration, for all type of task, will be modeled by a fuzzy duration. Finally, the most delicate disturbance, that may happen, is a new task arrival which has to be inserted in the current schedule. Its parameters are of course subject to estimation, and there precision depend on the diagnosis exactness.

We introduce quickly the different work in the literature, which deals with the scheduling insertion problem. Monostrie and *al.* have made a state of the art of the proactive approaches and reactive approaches with disturbance [7]. Kis and *al.* but also Gröflin and *al.* treat the tasks insertion problem in job-shop. They tried to minimize the scheduling total duration when a new task appears [8]. In the Resource Constrained Project scheduling Problem, known as RCPSP, Artigues and *al.* consider a dynamic approach which is based on a first and static schedule [9]. A project scheduling bibliography under uncertainties had been published by Herroelen and *al.* [6]. It considers reactive approaches, robust or proactive approaches and approaches with stochastic data.

3.3 Scheduling using fuzzy logic

Scheduling using deterministic data are useful in context where there is no source of uncertainties. However in an industrial context and especially in a maintenance environment, data used are often estimated and have a degree of uncertainties. Solutions given by a deterministic scheduler will then not be feasible and far from the real optimum. That is why uncertainties have to consider during the modeling phase. As in many scheduling context, the main source of uncertainties is the processing time of the different tasks. The nature of each maintenance process task is fuzzy. For example the corrective maintenance tasks depend of a correct diagnosis. The notion of fuzzy is a generalization of the classical set notion where the membership of an element to a set is true or false. Fuzzy logic was introduced by Zadeh, to deal with problems where data are not deterministic [10]. Fuzzy set theory uses multi-valuated function to represent the membership of an object in a set rather than true or false in the classical binary theory. It quantifies how an element is considered as being in a set. Guiffrida and Nagi published a survey on fuzzy set theory applications in production [11]. A great number of work used fuzzification to represent due dates or processing time and makespan. Job earliest/latest starting dates in maintenance being dependant of a fuzzy release date are of course fuzz. The tasks completion time depending of tasks predecessor are then also fuzzy. Many works had been done concerning job-shop and flow-shop problems in fuzzy environment [12]. Multiobjective scheduling problems are source of research for fuzzy theory [13].

4 MODEL

4.1 Tasks

Tasks characteristics are modeled as follow: if the task *j* is a preventive maintenance tasks:

- $p_j^{\,p}$: standard duration of the preventive task *j*.
- $\tilde{r}_j^{\,p}$: fuzzy release date of the preventive task *j*. Uncertain release date of operation *j* is modeled by a fuzzy set $\tilde{r}_j$ with a triangular membership function given by a triplet (r_j^1, r_j^2, r_j^3).
- $\tilde{d}_j^{\,p}$: fuzzy due date of the preventive task *j*. Uncertain due date of operation *j* is modeled by a fuzzy set $\tilde{d}_j$ with a triangular membership function given by a triplet (d_j^1, d_j^2, d_j^3).

If the task *j* is a corrective maintenance tasks:

- $\tilde{p}_j^{\,c}$: fuzzy standard duration of the corrective maintenance task *j*. Uncertain processing time of operation j is modeled by a fuzzy set $\tilde{p}_j$ with a 4 points shape membership function given by a quadruplet (p_j^1, p_j^2, $p_j^{2'}$, p_j^3).
- $r_j^{\,c}$: release date of the corrective maintenance task j. Generally equal to the corresponding breakdown date.
- $d_j^{\,c}$: due date of the task *j* (this value is based on the current availability of the equipment concerned).

And for each maintenance tasks:

- w_j : penalties which could be claimed if the treatment of the task *j* is not performed on time.

4.2 Human resources

The maintenance service is composed by *m* human resources (*i=1...m*), characterized by a competence profile. Relative speeds do not depend only on the tasks. Each resource has a fuzzy corresponding qualification level for each task. Operators will perform them more or less quickly. The fuzzy duration of the job *j*, by the human resource *i* is denoted by $\tilde{p}_{ij}$. With:

$$\tilde{p}_{ij} = f\left(\tilde{p}_j, \tilde{C}omp_{ik}\right), \forall i \in \{1,\ldots,m\} \qquad (2)$$

Where $\tilde{C}omp_{ik}$ is the fuzzy competence rate set of resource *i* in the competence which is required to achieve the type of task *k*. $\tilde{C}omp_{ik}$ has a triangular membership function given by a triplet ($Comp_{ik}^1$, $Comp_{ik}^2$, $Comp_{ik}^3$).

It can be represented with a matrix in which, for each different kind of job, where the corresponding rate to the required competence can be found.

$$\begin{bmatrix} \tilde{C}omp_{1,1} & \cdots & \tilde{C}omp_{1,k} \\ \vdots & \ddots & \vdots \\ \tilde{C}omp_{m,1} & \cdots & \tilde{C}omp_{m,k} \end{bmatrix}$$

The treatment duration of two different tasks by two different resources enables observing that for one kind of task, a resource can be more powerful than one other, whereas, for the second task, it is the second one which is the most efficient.

In our problem, we will considered a current schedule (already computerized) which integrates *n* tasks that had been already assigned to *m* human resource. The current schedule can be modeled as a graph. The graph is a unit of branches which represent each one a human resource schedule. They are composed of nodes which represent tasks and arcs which are the potential constraint between to tasks (precedence). The valuations of arcs are the duration of the origin task. Tasks are placed between a fictive beginning task *B* and fictive end task *E*. There is no link between branches, because resources work independently.

4.3 Variables

The variables of our problem are the following ones for each task *j*:

- t_j (*j=1…n*): planning date of the task *j*.
- x_{ij} (*j=1…n and i=1…m*): 0-1 value representing the tasks assignment. $x_{ij}=1$ if the task *j* is assigned to the resource *i*, else $x_{ij}=0$.
- $\tilde{C}_{ij}$ (*j=1…n and i=1…m*): fuzzy completion time of the task *j*, assigned to a resource *i* date of the task *j*.
- T_j (*j=1…n*): lateness of the task *j*.
- *ESj* (*j=1…n*): earliest starting date of the task *j*.
- *LSj* (*j=1…n*): latest starting date of the task *j*.
- *R*(*S*): robustness measure of a schedule *S*.

4.4 Constraints

Each task has to be assigned only once to only one resource:

$$\sum_{j=1}^{n} x_{ij} = 1, \forall i \in \{1,...,m\} \tag{3}$$

A task *j* cannot be planned before the equipment *i* is available:

$$\forall j, t_j \geq r_i \tag{4}$$

4.5 Objectives

In order to consider corrective maintenance, we have to insert dynamically tasks in a current schedule. However it is difficult to insert tasks in a schedule which is subject to variations between the proposed one and the reality. In order to find new task insertion solutions, we have to determine which place are the most flexible and consequently propose the most robust schedule (the less sensible to variations). The fact to propose solutions taking into account variations by anticipating them, signify that our scheduling approach is proactive. Tasks which are finished late decreasing the equipment availability ratio imply that we have to minimize the total weighted tardiness.

$$\min \sum_{j=1}^{n} w_j T_j \tag{5}$$

The aim of our work being to schedule human resources activities, our methodology will take into account their individual performances to find the best resource for each task. But it will also consider the existing workload in order to distribute activities between employees. Others objectives will then be:

- To minimize the number of late tasks:

$$\min \sum_{j=1}^{n} U_j \tag{6}$$

- To balance and to minimize the workload, by minimizing the standard deviation between resources:

$$\min \sigma = \min \sqrt{\frac{1}{m} \sum_{i=1}^{m} (CP_i - \overline{CP}_i)^2} \tag{7}$$

- To minimize the number of task which could have a new assignment (assigned to a new resource):

$$\min \sum_{j=1}^{n} \text{mod}_j \tag{8}$$

5 PROBLEM RESOLUTION

5.1 Tardiness penalties and robustness measure

In order to obtain the completion time of each job, fuzzy operation have to be used. The fuzzy task duration adds to the fuzzy release date will allow to obtain the fuzzy set representing the completion time computation. As the difference with [14] where there is precedence constraint, here the fuzzy completion time is obtained with:

$$\tilde{C}_{ij} = \tilde{\max}\left(\tilde{r}_j, \tilde{C}_{i,pred(j)}\right) \tilde{+} \tilde{p}_{ij} \tag{9}$$

Where $\tilde{+}$ is the fuzzy addition operator and $\tilde{\max}$ is the fuzzy maximum operator.

Robustness measure is used to show the difference between solutions which are subject to uncertainties. It evaluates the lateness potential of a solution. Task lateness is defined by the fact that its completion date is reached after its due-date. In other words, if the task is not finished at the due-date means that it will be late. In classic logic, the fact that a task *j* is not finished, correspond to the interval $\left]-\infty ; \tilde{C}_j\right[$. If the task is not finished before the interval $\left[\tilde{d}_j ; +\infty\right)$, the task will be late. An intersection between these intervals means that there is lateness. In fuzzy logic the completion date and due-date will be the fuzzy intervals $\tilde{C}_j$ and $\tilde{d}_j$. Intervals previously obtained will respectively have for membership functions will then be $\mu_{\left]-\infty;\tilde{C}_j\right[}$ and $\mu_{\left[\tilde{d}_j;+\infty\right)}$ [12].

A robust schedule is defined as being insensitive to disturbances. Leon and *al.* developed a methodology to measure scheduling robustness and to realize robust schedule in case of disruption due to control [15]. A schedule robustness measure had been defined too by Chen and Muraki for the scheduling in batch processes [16]. An adaptation of this measure is defined as being the average degree of conflict on the individual constraint between a task and it's due date constraint. Where, the fuzzy membership function $\mu_{lateness}(t)$ shows the potential lateness and is obtain from the equation 10. However, the robustness represents the fact that his performance is few sensible to data uncertainties and variations. The fuzzy membership function $\mu_{in\_time}(t)$ is then obtained from the equation 11. Since all constraints have not the same importance we introduce the *weight$_j$* penalty factor (described in the equation 12) to weight the different conflict in the equation 13. *n* denotes all the different conflict locations within the schedule *S* and *R(S)* will then give its robustness level. A robust schedule will have an index *R(S) = 1* contrary to a schedule which is sensible to variation which will obtain *R(S) = 0*.

$$\mu_{lateness_j}(t) = \min\left(\mu_{\tilde{C}_{ij}(t)}, \mu_{\tilde{d}_j(t)}\right) \tag{10}$$

$$\mu_{in\_time}(t) = 1 - \mu_{lateness_j}(t) \tag{11}$$

$$weight_j = w_j / w_j^{\max} \tag{12}$$

$$R(S) = \frac{1}{j}\sum_{1}^{j}\left(\mu_{in\_time_j} * weight_j\right) \tag{13}$$

5.2 Dynamic insertion methodology

In that part of the paper we are interested by introducing a new task in a current scheduling. New tasks being mainly maintenance corrective tasks, their characteristics are stochastic as long as a diagnosis has not been done. When a new task has to be inserted and, when there is not any obvious solution, to ways are possible. The first one consist in generated completely a new static scheduling. This methodology does not take into account potential disturbance for employees which have a new planning. The second one consists in searching new scheduling in adding the few modifications to the current schedule. This kind of approach allows disturbing the less possible the existing planning and then the employee organization.

```
Begin
  Initialization (ES) ;
  While nb_search < nb_search_max  do
      nb_search ++ ;
      S  ←     Random_choice(ES) ;
      Eval  ←  Evaluation(S) ;
      nb_descent  ←  0 ;
      While (nb_descent < nb_descent_max) or (find ==false)  do
        nb_descent++ ;
        S'  ←  neighbough(S) ;
        If  ES !≺ S' then
              nb_descent ← 0 ;
              ES  ←  S' ;
              If S' ≺ ES  then
                S  ←  S' ;
              End if
              Suppression_dominated_solutions(ES) ;
        End if
      End while
      While (nb_jump < nb_jump_max) or (find ==false)  do
        Nb_jump++ ;
        S'  ←  Jump(S) ;
        If  ES !≺ S' then
              nb_jump ← 0 ;
              ES  ←  S' ;
              If S' ≺ ES  then
                S  ←  S' ;
                Find  ←  true ;
              End if
              Suppression_dominated_solutions(ES) ;
        End if
      End while
  End while
End
```

Algorithm 1: Multi-criteria scheduling methodology

The proposed method is based on a neighborhood search. This method is principally based on local descent and on the kangaroo methodology in order to avoid local locking.

The algorithm is composed of de variables:

- *S:* Solution that we try to improve.
- *S':* Solution on which we are working on.
- *nb_search*: Number of pass in the algorithm.
- *nb_descent*: Number of local search.
- *nb_jump*: Number of jump with to go out of a local optimum.
- *boolean find*: find==true means that a jump allowed to find a improving solution.

But also of data:

- *nb_search_max*: Destinate to limit the number of pass in the algorythm.
- *nb_descent_max*: Destinate to limit number of local search.
- *nb_jump_max*: Destinate to limit the number of jump with to go out of a local optimum.

And of functions:

- *Initialization(S)*: Find the initial solution. This one is found by trying all the insertion possibilities of the new task in the current scheduling. These solutions (or scheduling) are then compared and the best one is kept.
- *Evaluation(S)*: Give the evaluation of S following criteria used.
- *neighbough(S)*: Find a neighbour of S by exchanging two tasks randomly chosen.
- *Suppression_dominated_solutions(ES)*: suppressed dominated solution of ES.

The fact to proceed stochastically to tasks exchanges rather than to a stochastic displacement, allow conserving a certain balancing of the load. The balancing of the load is usually made with the total duration of tasks assigned to through the number of tasks.

5.3 Data generation

We carried out a computational experiment on a Pentium IV 3.00GHz considering tests obtained by generating randomly the p_{ij} values. p_{ij} values are principally obtained by the combination of the basic tasks' duration (in time unit) which is an integer from the uniform distribution [1, 7200]. This duration is multiplied by the competence level of the resource in the corresponding competence. For each task, a corresponding competence is determined by an integer from the uniform distribution [1, 3]. It refers for each resource to a level, which is a real from the uniform distribution [1.01, 2.00], in this competence. The parameter *nb_search_max* had been fixed to 5, *nb_descent_max* to 5 and *nb_jump_max* also to 5. Concerning the complexity of the problem, multi-objectives optimization problems are very complex and the complexity besides the combinatorial aspect comes from the fact that there is no single optimal solution for these problems, but rather a set of trade-offs called efficient solutions or Pareto-optimal solutions. The size of the space of research *SR* is obtained as follow :

$SR = \dfrac{n!(n-m)!}{m!} \times \prod_{i=1}^{m} n_i!$ with n_i the number of tasks assigned to the machine *i*.

5.4 Example

We studied the dynamic insertion of tasks through three different existing scheduling cases. Solutions obtained will be compared with a static heuristic which had been presented in by Marmier and *al.* in [2]. This heuristic re-built completely the schedule. In certain cases it is interesting to note that the heuristic proposition is totally dominated by propositions obtained with the multi-criteria research. In all cases, the proposed solutions by the multi-criteria research are best on almost one of the criteria. In all cases too, this methodology allow to change of assignment less tasks than with a static rescheduling.

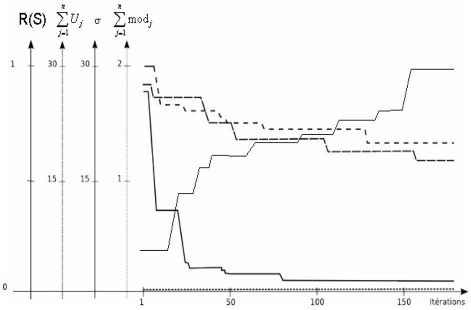

Figure 1: Convergence of the evaluations

The figure 1 shows the best results, following each criterion, during the insertion of one task. That's not one solution but it shows the good convergence of the set of solutions.

We treated the case of a schedule of 40 tasks assigned to 3 resources in which 10 new tasks have to be dynamically inserted. This case will off course be compared to the results obtained with the static heuristic. Results obtained following the weighted total tardiness had been evaluated with the robustness methodology presented before. The 10 new tasks will then be dynamically inserted in the existing schedule. That the final simulation of the obtained solutions which allow results following all criteria.

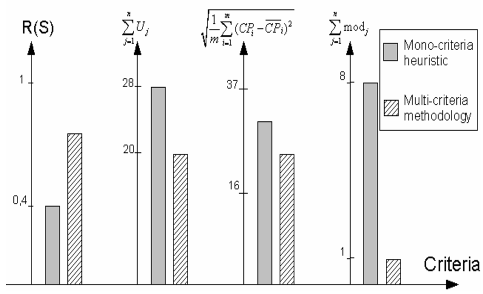

Figure 2: Comparative results diagram

As observed on the figure 2, results of this evaluation allow .hen to show that the obtained solution with the multi-criteria research dominated completely the solution obtained with the heuristic.

5.5 Discussion

Results obtained had been compared with this obtained in [2]. This works presented a mono-criteria heuristic allowing the task assignment to human resources under competences constraint. The obtained results evaluation from this heuristic, following criteria used in this study, allow comparison. It shows, off course, that the fact to privilege a criterion gives solutions with bad results following others criteria. The fact to change task assignment is disturbing for employees. Solutions obtained with the presented method show that a good solution can be obtained by moving fewer tasks than with the heuristic.

6 CONCLUSION

We presented here a multi-criteria methodology to insert dynamically new tasks in an existing schedule. This method gives to the maintenance manager a set of solutions with their evaluations following different criteria. Fuzzy logic has been used to deal with uncertainties and to evaluate potential penalties. The originality of our methodology is to propose to the manager a set of non-dominated solutions. This one, following its own perception of the criteria importance will have to choose one of them. We compared this methodology to results obtained with a static scheduling methodology. Sometime, heuristic solutions are totally dominated by our methodology. In all cases, multi-criteria method gives best solutions following at least one criterion. In all cases too, it allows to change fewer task assignment.

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